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Methodology to select the best part presentation in cobotics

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Abstract

The collaborative robot (cobot) is a technology contributing to the industrial revolution Industry 4.0. Indeed, cobots' flexibility and their easy-to-use solutions fill a gap with traditional robots to robotize manufacturing of products with low volume and high mix profiles. Parts needed to manufacture a product must first be presented to the cobot, so that afterwards it can perform operations such as assembly. The paper classifies the current part presenters. Then, a methodology is proposed to select the best presenter based on the characteristics of the parts and the workstation. To be aligned with markets requiring a high mix of products frequently renewed, the development times for part presenter design and for cobot programming are new data to select the best presenter. Indeed, at every part redesign, the part presenter changes and the cobot is reprogrammed. These two times are depreciated based on the lifespan quantity of the part. Lifespan quantity is the number of the same parts, which are dropped-off on the part presenter during the part's lifespan, i.e. until its redesign. A concrete industrial use case is explained to test the methodology. Results conclude that a tray pattern is the best part presenter, except for parts with low lifespan quantity. Lifespan quantity of the part appears to be a significant parameter when deciding the best part presenter.

1. Introduction

A new industrial revolution towards Industry 4.0 has been ongoing for ten years with the introduction of new technologies. Automation, integration, collaboration, flexibility, safety and security are the main fields of research attention [1]. New technologies are also going to impact the management of shop-floor operators in terms of requirements and demand [2]. In a new paradigm of reconfigurability requested by the markets [3], system has to evolve. Collaborative robots, named cobots, have been clearly identified as promising tools for enabling human operators to bring flexibility to the robotized workplace [4] [5] [6] and to increase efficiency and ergonomics [7]. The existing literature focuses on technical solutions to increase safety, productivity and decrease costs [8]. In this article, a mathematical model was made comparing collaborative and traditional robotic assembly by measuring the objectives of throughput and unit direct production costs. However, Faccio et al. [8] concluded that development costs should be addressed by further research. The shop-floor operators in a human-robot collaboration have to be able to change the full manufacturing configuration [9] quickly. As though by Gambao et al. [10] through their new generation of human-robot solutions, new paradigms and approaches have to be developed for handling technology.

Collaborative robots allow a human-robot collaboration (HRC). This HRC takes place inside workstations manufacturing semi-finished or finished products, which are fed from warehouses. Bortolini et al. [11] divided the material feeding, when dealing with the design of the assembly operation in the frame of Industry 4.0, into storage (packaging type and dimensions) and feeding policy (line side stocking, kitting feeding, or kanban feeding). Once the part has been fed to the workstation, the part must be presented to the manufacturing resources. In the paper context, the resources are specifically cobots, performing some operations of picking and placing. To perform these operations, a cobot needs to grasp parts reliably and efficiently. The parts are presented in the workstation thanks to a part presenter, waiting for the picking by the cobot. The question comes regarding the best selection of part presenter.

Boothroyd [12] defined the purpose of part presentation as to present the parts in the same orientation at the same location. Indeed, the cobot itself with a simple gripper cannot grasp the part if the part is not in a given position and orientation. However, with the recent development of new technologies, some high-tech devices can give some senses to cobots, through vision systems or torque sensors. Part presentation is consequently important for the efficiency of the cobot system. Best practice would be to include the design of the part presenter during its development at the design phase to avoid rework, delays and cost. Indeed the cost of part presentation can significantly influence the total manufacturing costs by 10%-30% [13] [14]. Part dedicated-fixtures do not bring the flexibility requested to deal with a variety of work-pieces. So improving fixtures can help reduce unit costs. Moreover, the optimum fixture can evolve during the lifespan of the part. The fixture at the start of a new product may differ from maturity step.

Consequently, part presentation is a link between part feeding and the manufacturing workstation. The introduction of new technologies through Industry 4.0 influences part presentation. Moreover, reconfigurability is required by the markets demanding frequent product redesigns, so shorter part life cycle. Collaborative robots are a response to it. The objective of the paper is to determine if a shorter part life cycles impacts the choice of the best part presenter, which feeds a cobot. Reconfigurability being an objective, the performance criterion to select the best part presenter is the time spent due to a new part presentation device (presenter redesign, cobot programming, change of part loading). The methodology used for the research is to develop a complete method (flowchart, inputs, processes, outputs) selecting the best part presenter, and then to test it with a concrete case. The paper is organized as follows. Section 2 presents a literature review. Section 3 organizes the characteristics of part presenters, parts, and manufacturing operations. Based on these characteristics, a method is suggested in Section 4 to select the best part presenter. In Section 5, this method is tested through an industrial use case. Section 6 concludes this paper and points out the stages to follow.

2. Literature review

The literature review starts with part feeding, which is the process before part presentation as explained above. Then, literature review is extended to other relative topics, which are part disorder and fixture & jig. Motivations for these topics, definitions and literature reviews are detailed hereunder.

Part feeding is transporting a part from the warehouse into the manufacturing workstation. The existing literature concerning part feeding is really intensive [15]. Linked with this paper objective, Battini et al. [16] and Caputo et al. [17] evaluated the best feeding policy (kitting, line storage, and just in time delivery) according to the part features. Part presenter can be supplied by one of the three above part feeding strategies. Hanson et al. [18] experimented with the time spent for fetching parts and for assembling parts between the feeding principles of continuous supply and kitting. Time spent searching parts and distance are two factors influencing the fetching time.

Literature concerning part presenter and its design choice is cost-oriented. Boothroyd [12] described a decisional economical graph to select the right part-presentation system. The costs taken into account were the investment cost (general-purpose equipment plus part-dedicated tooling) and the labour cost. Four different automatic feeder systems were studied: vibratory bowl feeder, Hitachi multipart feeder (vibratory system and vision system), Salford multipart feeder (interchangeable mechanical tooling) and double-belt feeder. Based on cycle time and quantity to be manufactured during payback period, the best feeder system among the four can be selected on a graph calculated by the authors. Below 6500 pieces, none of the automatic feeders was economically interesting. Ho and El-Gizawy [19] also performed an analysis on economic interests based on the costs of basic equipment, tooling and changeover.

When a part is dropped off on a surface as in a part presenter, the part can be located in various positions. Positions can be from well-defined ones to fully random ones if the degrees of freedom are not constrained. Sanderson [20] studied mathematically part disorder by defining the concept of part entropy. Chirikjian [21] extended this concept to the multiple interacting parts. The entropy H was calculated from the probability distribution of part position and orientation. If H is equal to zero, there is no ambiguity of the part position.

Fixtures and jigs are sometimes mentioned in literature when searching publications on part presenters. Nevertheless, fixtures are really different to part presenters as they clamp one or few parts with technical devices. The functions of a fixture are locating, supporting and clamping, before manufacturing or measurement operations. Bi and Zhang [13] detailed the design of flexible fixtures. The fixture has not to be mixed up with jigs, which are devices to guide another tool for repeatability purposes (e.g. drill). The flexible strategies for fixture systems are either a modular structure (modules can be adapted depending on the part), or a single structure but with material phase-change (e.g. temperature-induced) or with adaptive clamps (internal variables fitting with various parts). As these fixtures are somewhat complex, dynamic simulation can help to design the part feeders and its configurations [22]. The fixture design and its computer-aided tools were extensively addressed by the researchers [13].

As a conclusion of the review, as opposed to part feeding literature, part presentation has been less attractive for the researchers for a long time. This can be easily explained: traditional robots are used for high volumes of production, so the choice for part presentation is obviously some sophisticated devices to achieve very high throughput. But it is not the case with cobots dealing with low personalized throughput. On top of that, cost impacts are often addressed, meanwhile the impact of development has not been addressed. The novelty of the study is to explore the impact of this development time on part presenter choice. Indeed, development is a key point for reconfigurability objective as referenced in the introduction section. Consequently, this paper aims to continue previous research to select the proper part presenter, for cobots in the scope of Industry 4.0, including the development of the part presenter as a new criterion of selection.

3. Manufacturing characteristics

3.1. The characteristics of the part presenter

Boothroyd [12] breakdown the part presentation into two categories: single location (robot grips part always at the same location) or multiple location (robot grips part based on a pre-determined pattern or randomly thanks to a vision system). Applying the part entropy methodology [20], these two categories (single and multiple location) have different impacts on part entropy and reconfigurability. This leads to switching from Boothroyd's two categories to three (single, multiple, random). The study keeps this taxon 'location' with these three possibilities.

In order to select the best part presenter, the first step is obviously to know the potential part presenters already used by robots and cobots worldwide. Fig.1 classified them using a Function Analysis System Technique (FAST) graph. A FAST graph organizes the functions that need to be performed by the process into "how?/why?" relationships. The right side of the graph consequently lists the existing technical solutions to reach the part presentation objective. The loading of the parts into the presenter can be either on-line (no stopping of the robot) or off-line (stopping of the robot required). Additionally to the taxon 'location' previously explained linked to part entropy, the taxon 'energy' is first introduced on the left side. Indeed, the graph is divided into two sets depending if energy is required. The following paragraphs list and detail this new classification of the part presenters using the taxons 'energy' and 'location'.

NO ENERGY REQUIRED: The following part presenters are systems without electronic or moving devices. The design is only mechanical, quite quick (a few hours), and cheap (hundreds of euros). 3D printing can produce them. Their contents (number of parts) are limited. Possible part presenters are:

a) One-piece structure, to present one part at once. It is the simplest way;

b) Gravity track, a structure so that parts can easily slide once part at the bottom is picked up. It is one dimension structure, and may be two-dimension one if the part is cylindrical;

c) Tray, a two-dimension structure;

d) Box, a three-dimension structure. It is mandatory that parts can be stacked one above the other.

REQUIRING ENERGY: The following part presenters require electrical or pneumatic energy. Indeed, they are complex systems with different moving devices. Their design is consequently quite long (a few weeks) and expensive (some thousands of euros or even more). Qualified multidisciplinary

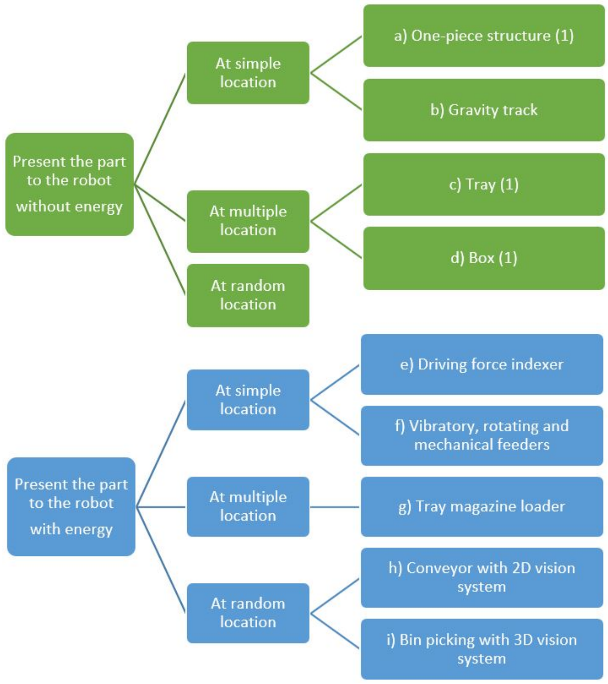

Fig. 1. Function analysis system technique. (1) Cannot be supplied online

teams, often externalized, design them. The set-up activities when changing parts are time-consuming. However, they allows high throughputs. Possible part presenters are:

e) A driving force indexer with a simple motor can rotate or translate a tray of parts to locate each part in the same place during each manufacturing cycle;

f) Vibratory, rotating and mechanical feeders are special-tooled systems. The bulky parts in a container are then positioned 1-by-1 through a vibration or well-engineered mechanism and then moved to the workstation through an escapement. This system is dedicated to a given part (driven by the geometry and weight barycentre of each part). A vision system may be integrated;

g) Tray magazine loader can present a new full tray when the previous one has been emptied by the process;

h) Conveyor carries linearly the parts (randomly oriented and positioned) on a belt until a specific place triggered by sensors. An appropriate 2D vision system detects the parts and transmits the positions precisely to the cobot so that the cobot can pick up each part. The parts at the entry of the conveyor or directly below the vision system may come from a vibratory plane;

i) Bin picking: a bin contains the bulky parts. The gripper of a cobot picks up appropriately each part through a 3D vision system. It leads to complexity to avoid some picking errors or to crushing parts.

A part presenter with energy is technologically more complex but is more efficient. It will consequently be dedicated to

Table 1. Impact of the exclusive part properties.

Exclusive part characteristics	a) One-piece	b) Gravity track	c) Tray	d) Box
Regular shape for pattern logic	Optional	Mandatory	Mandatory	Mandatory
Stackable	Optional	Optional	Optional	Mandatory
Slide on an inclined surface	Optional	Mandatory	Optional	Optional
Cannot overlap with other identical part	Optional	Mandatory	Optional	Optional
Cannot tangle with other identical part	Optional	Mandatory	Optional	Optional

parts with a high volume of production and low variety, to avoid reworking the design of the presenter. This energy-required part presenter is an antagonist to the flexibility targeted with the usage of cobots in HRC. Nevertheless, a vision system may reduce the reworking impact as only reprogramming would be requested. Traditional industrial robots usually perform operations in a context of fixed special purpose automation dedicated to high production volumes and a low variety of products. Whereas, the robots associated with human operators (semi automation) are efficient for mid production volumes and a mid variety of products [23]. It is specifically adapted to shorter life cycle products in the current economy [24]. For this semi automation, which is clearly the objective of collaborative robots, the design of the parts and the finished products evolves quickly. Consequently, the paper focuses only on the part presenter not requiring energy. On top of that, doing part presentation without energy contributes to the energy challenges of the 21st century.

3.2. The characteristics of the parts

The objective of the part presenter is to present the part easily for the gripper. Each part has its own graspability, i.e. the quality of being graspable by a gripper. It is impacted by the characteristics of the part. Malik and Bilberg [25] did a systematic framework for cobot deployment in assembly cells. Their process requirements include the definition of the physical properties of the parts: form, shape, dimensions, tolerances, material, weight, size and surface finish, etc.

These physical properties are added to two other ones more specific to part presenters, leading to the following three types of part characteristics:

- Physical properties: shape, dimensions with their tolerance intervals, material, weight, surface finish
- Properties making presenter design easier: narrow tolerances to locate accurately and isostatically, shape allowing error-proofing system, symmetric part (cylindrical etc.)
- Exclusive properties for some presenters: regular shape for pattern logic, stackable, can slide on an inclined surface, cannot overlap with other identical part, cannot tangle with other identical part

These latter exclusive properties drive the choice for some part presenters. For example, parts must be stackable to be stored in box. Table 1 presents the analysis for each part presenter.

Table 2. Workstation autonomy based on the level of collaboration.

Level of collaboration	Situation of human and cobot	Workstation autonomy
Coexistence	Work alongside but not shared workspace. Human does not interact with cobot during operating time	High. The workstation works until the part presenter is empty
Synchronized	Work sequentially on one given product	One-piece flow. The human can feed from bulk the workplace
Cooperation	Shared workspace, non-simultaneous tasks, separate product	Medium. The cobot needs to be autonomous but if needed the human can feed from bulk the workplace
Collaboration	Work simultaneously on the same product	One-piece flow. The human can feed from bulk the workplace

3.3. The characteristics of the manufacturing workstation

When designing the workstation and its part presenters, one important data is the expected cycle time of the workstation, as a step in a global workshop. It is linked with the takt time from Lean methodology. Moreover, depending on the product routing and the abilities of the agents (i.e. humans and robots), a level of collaboration between them is defined. The levels of collaboration between the human worker and the cobot can be multiple [26]. Bauer et al. [27] defined four typologies: coexistence, synchronized, cooperation, or collaboration. It impacts the requirement regarding workstation autonomy as analyzed in Table 2 in terms of workstation autonomy. The workstation autonomy ($t_{workstation-autonomy}$) is the time during which the workstation can work without human intervention. Based on cycle time and the level of collaboration, the optimum workstation autonomy can be computed.

Another requirement concerning the manufacturing workstation is the available physical area for part presenters. The area is key data as the usage of cobots improves the footprint, by avoiding cage fencing when applications are safe. A reduced area, leading to shorter and quicker flows and lower fixed costs,

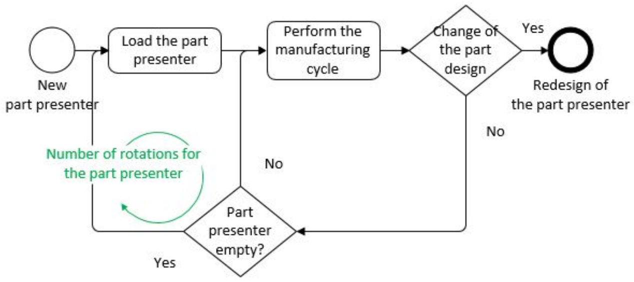

Fig. 2. The operating flow.

is a strategic advantage. However, a reduced area for part presenters with fewer parts would decrease workstation autonomy. The optimization of the area is measured with the indicator named Area Efficiency as given by Equation (1).

$$Area\ Efficiency = \frac{Area_{one-presenter}}{Area_{one-part} \times c} \tag{1}$$

where (c) is the capacity of parts inside one part presenter.

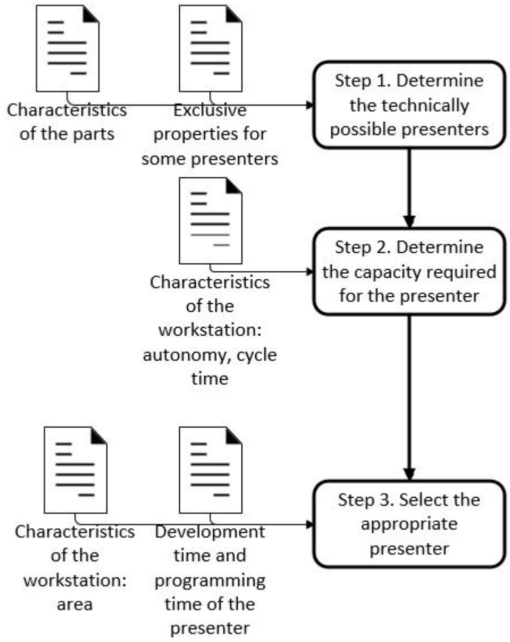

Fig. 3. Methodology to select the appropriate presenter.

4. Method

Before explaining the methodology, the paragraphs will explain the development time and lifespan load time.

4.1. The development time

When a new presenter has to be (re)designed due to part evolution, there is a development time (DT). In a previous study [28], we divided a project into process engineering, implementing and operating steps. Development time is the duration of process engineering and implementing operations. For a new part presenter, Equation (2) concerns the design of the part presenter (t_{design}) and the programming of a cobot ($t_{programming}$). These two times are directly linked to the complexity of a part presenter.

$$DT = t_{design} + t_{programming} \tag{2}$$

4.2. The lifespan load time

During the manufacturing cycle, parts are grasped by the cobot. So the number of parts in the part presenter decreases until it is empty. At that time, as shown in Fig. 2, the part presenter is to be reloaded, either by replacing it by a new full presenter or by refilling it with parts depending on the design of the presenter. This reloading is called a rotation of part presenter. Equation (3) calculates the number of rotations of the part presenter (r).

$$r = q/c \tag{3}$$

where lifespan quantity (q) is the number of the same parts, which are dropped-off on the part presenter during part's lifespan, i.e. until its redesign.

Each part presenter requests a time ($t_{lifespan-load}$) to load it fully during all rotations (r) as in Equation (4).

$$t_{lifespan-load} = r \times t_{one-rotation} \tag{4}$$

where $t_{one-rotation}$ is the time to change the part presenter for an offline load, and the time to load q parts in the presenter for an online load. For the purpose of the calculation, all part presenters are considered to have the same exposure for the picking (angle, height). The dichotomy from Boothroyd et al. [29] is used for the study: picking with one hand vs. picking with two hands. The picking time is valued with an average of previous studies [29] [30] [31], so 2 seconds to load one part with one hand and 4 seconds if hand loading requires two hands. The autonomy of the workstation, i.e. until the part presenter is empty, is defined in Equation (5).

$$t_{workstation-autonomy} = c \times CT \tag{5}$$

where CT is the cycle time of the manufacturing operation itself.

Table 3. Characteristics of the part, a cylinder barrel.

Shape	parallelepiped
Dimensions	60 mm x 60 mm x 76 mm
Tolerances	0.1 mm
Material	Aluminum
Weight	232 g
Surface finish	exterior: extruded, interior: machining
Narrow tolerances to locate accurately	Yes
Shape allowing error-proofing system	Yes
Symmetric part (cylindrical etc.)	Partly
Regular shape for pattern logic	Yes
Stackable	Yes
Slide on an inclined surface	Yes
Cannot overlap with other identical part	Yes
Cannot tangle with other identical part	Yes

Operating lifespan (OT) can be calculated as in Equation (6) if one part is requested at each cycle. Considering DT and OT, the times impacting the choice of the presenter are t_{design}, $t_{programming}$, and $t_{lifespan-load}$. Only $t_{lifespan-load}$ depends on the lifespan quantity of the part.

$$OT = t_{lifespan-load} + CT \times q \tag{6}$$

4.3. Methodology to select the part presenter

The data defined in the above paragraphs are used through a methodology to select the part presenter as detailed in Fig. 3.

Step 1: a first selection is made based on the characteristics of the parts and the exclusive properties for some presenters. As explained previously, some presenters are not possible due to some technical characteristics.

Step 2: the required capacity of the presenter is a key data. It is determined based on the characteristics of the workstation, in terms of autonomy and cycle time.

Step 3: this last step allows us to select the appropriate part presenter. Development and programming times are calculated to evaluate their impacts during the reconfigurability period.

5. Results from use case

In order to check the methodology of part presenter selection, a concrete industrial use case has been used. The manufacturing process is the assembly of a pneumatic cylinder as detailed by Quenehen et al. [28]. Its bill of material has six components, including a cylinder barrel. A cylinder barrel is selected for the study of part presentation because, as explained in *Step 1*, there are no blocking characteristics to design the four part presenters (one-piece, gravity, tray and box). Also, its shape is simple enough to avoid any impact of a complex gripper on the design of the part presenter. The workstation is composed of a collaborative robot sharing the assembly tasks with a human operator. The objective is to use the above methodology and analyze how the various part presenters differentiate themselves.

Step 1: The characteristics of a cylinder barrel are assessed in Table 3 along the criteria defined in the methodology, including the exclusive part properties for some presenters from Table 1. Based on this comparison, *Step 1* concludes that all part presenters are technically possible for the concerned part, which is a cylinder barrel.

Step 2: This step is to calculate the required capacity of the part presenter. The sequence of assembly is already determined and shared between a collaborative robot and a human operator. The level of collaboration is classified as cooperation based on Table 2. Consequently, the capacity should be sufficient to match with the cycle time. The cycle time to assemble one cylinder is known to be 53 s with a waiting time of the operator at 5 s, which is compatible with the time to change a presenter with two hands (4 s based on the literature review previously quoted). Based on the upstream flow of parts inside the plant, the autonomy of the workstation is required to be 420 s. Following the method, the required capacity of the presenter is 420 s divided by 53 s, so 7.9 parts. This capacity is used later on at *Step 3* when the design of the part presenter is known and can be compared with this required capacity.

Step 3: The four potential presenters have been computer-aided designed (CAD) as reported in Fig. 4: one-piece (a), gravity track (b), tray (c), and box (d). Supervised fifth-year students in mechanical engineering with a basic background in CAD software and robotics have done the designs and evaluated the programming times of the cobot and the time to design the part presenters. Table 4 summarizes all these data. Concerning the required capacity from *Step 1* (7.9 parts), obviously a one-piece structure cannot satisfy it. The workstation, due to space restrictions on the shop floor, has a possible area of 300 mm x 200 mm for the presenter of cylinder barrel. The tray fits this area but its capacity is below the required one. The box is fully dimensional OK and has the advantage to optimize area (higher area efficiency) thanks to the two layers of parts. The gravity track has its length exceeding the required area length and is below the required capacity. The three impacting times following the method (design, programming, lifespan-load) have been calculated as per Fig. 5. In this figure, the best presenter is clearly linked to lifespan quantity. For a quantity of thousands, the one-piece structure or tray provides the less time-consuming solution. For a quantity of a few tens of thousands, boxes or trays are the best ones.

As a conclusion, each presenter has their own advantages and drawbacks. The tray looks to be the best compromise between all parameters, while the gravity track is the worst one. The box is very sensitive to lifespan quantity. If a high quantity is anticipated in the short term, it could be the best presenter.

Table 4. Data for the presenters designed in the use case.

	Presenter	Number of parts	Capacity	Length (mm)	Width (mm)	Height (mm)	Footprint (cm^2)	Area efficiency	Design time (s)	Program. time (s)
a)	One-piece	1x1	1	70	70	83	49	73%	7200	360
b)	Gravity track	6x1	6	350	63	130	221	98%	14400	360
c)	Tray	3x2	6	260	155	83	403	54%	10800	1800
d)	Box	2x2x2	8	182	157	112	286	101%	18000	7200

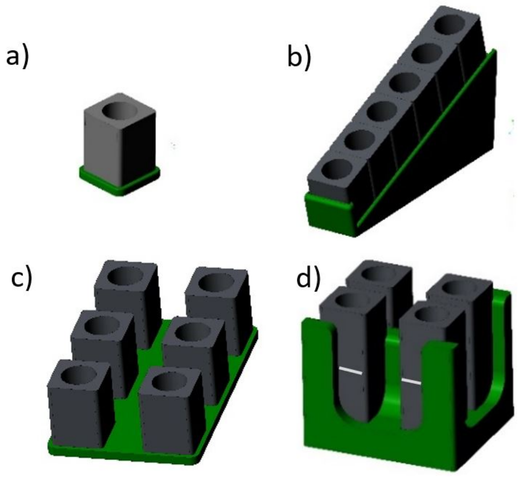

Fig. 4. Design of presenter with parts inside.

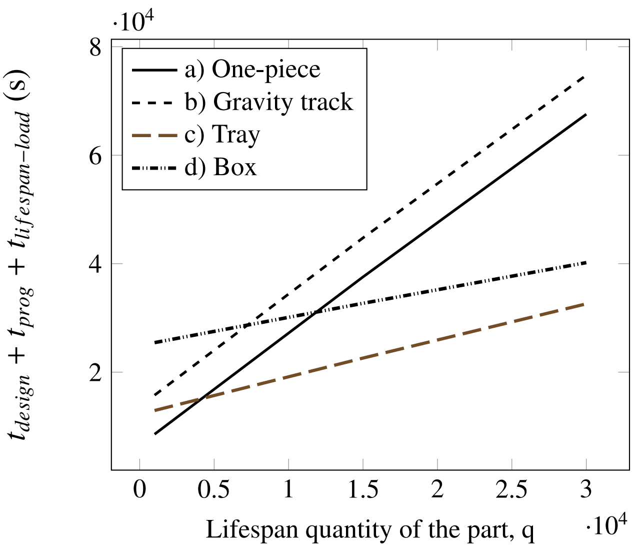

Fig. 5. Results.

6. Conclusions, limitations, further development

Industry 4.0 is ongoing worldwide, bringing new technologies such as cobots. At the same time, commercial markets request higher flexibility. Manufacturing has to manage in their workstations smaller product volumes, higher numbers of product variants, and more frequent product redesigns. In manufacturing workstations, cobots have to grasp parts from part presenters. Consequently, part presenters contribute to this flexibility. Previous studies, as detailed in the literature review Section, have addressed part presentation through economical analysis. This paper continues it by including the time of development as a questionable parameter. Indeed, this parameter influences the presenter redesign when the product is evolving. A methodology is proposed in order to list and analyze all parameters influencing the choice of the best part presenter. After having structurally listed all various part presenters, the study focuses only on presenters not requiring energy for flexibility and sustainability reasons. Regarding the objective of research (impact of shorter part life cycle on the choice of the best part presenter), the study demonstrates that lifespan quantity affects the choice of the presenter. The presenter is to be adapted all along the life cycle of the part, to be always the optimal one. An appropriate compromise is the usage of a tray as a part presenter, especially when the part life cycle is difficult to predict.

When considering the three impacting times (design, programming, lifespan-load), the resources of these tasks have not been differentiated. In a classical organization, the design would be performed by the manufacturing engineering department meanwhile programming and loading by the manufacturing operators and technicians. Further development would consider either the impact of different resources on the proposed methodology, or even investigate how to execute these tasks solely by manufacturing operators. It is perfectly aligned with the objective of Industry 4.0. Indeed this would lead to empower humans and let them focus on the true added value from their competencies and versatility versus robot's ones. Also, in this paper, part presenters requiring energy have not been addressed, as explained for reconfigurability and sustainability reasons. However, recent relevant advances on grasping objects using image processing and artificial intelligence address reconfigurability objectives [32]. Future research could include part presenters requiring energy in the developed method, while evaluating sustainability objectives too.

References

[1] Y. Liao, F. Deschamps, E. d. F. R. Loures, L. F. P. Ramos, Past, present and future of Industry 4.0 - a systematic literature review and research agenda proposal, in: International Journal of Production Research, volume 55, Taylor & Francis, 2017, pp. 3609–3629.

[2] M. Holm, The future shop-floor operators, demands, requirements and interpretations, Journal of Manufacturing Systems 47 (2018) 35–42.

[3] Y. Koren, The rapid responsiveness of RMS, International Journal of Production Research 51 (2013) 6817–6827.

[4] S. Jocelyn, D. Burlet-vienney, L. Giraud, A. Sghaier, Collaborative Robotics : Assessment of Safety Functions and Feedback from Workers

, Users and Integrators in Quebec (Report 1030), Technical Report, Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), Montréal, Quebec, 2017.
[5] B. Matthias, S. Kock, H. Jerregard, M. Källman, I. Lundberg, Safety of collaborative industrial robots: Certification possibilities for a collaborative assembly robot concept, Proceedings - 2011 IEEE International Symposium on Assembly and Manufacturing, ISAM 2011 (2011).
[6] D. Schonberger, R. Lindorfer, R. Froschauer, Modeling Workflows for Industrial Robots Considering Human-Robot-Collaboration, in: Proceedings - IEEE 16th International Conference on Industrial Informatics, INDIN 2018, 2018, pp. 400–405.
[7] A. Realyvásquez-Vargas, K. C. Arredondo-Soto, J. L. García-Alcaraz, B. Y. Márquez-Lobato, J. Cruz-García, Introduction and configuration of a collaborative robot in an assembly task as a means to decrease occupational risks and increase efficiency in a manufacturing company, Robotics and Computer-Integrated Manufacturing 57 (2019) 315–328.
[8] M. Faccio, M. Bottin, G. Rosati, Collaborative and traditional robotic assembly: a comparison model, International Journal of Advanced Manufacturing Technology (2019).
[9] C. Schou, O. Madsen, A plug and produce framework for industrial collaborative robots, International Journal of Advanced Robotic Systems 14 (2017).
[10] E. Gambao, M. Hernando, D. Surdilovic, A new generation of collaborative robots for material handling, in: 2012 Proceedings of the 29th International Symposium of Automation and Robotics in Construction, ISARC 2012, 2012.
[11] M. Bortolini, E. Ferrari, M. Gamberi, F. Pilati, M. Faccio, Assembly system design in the Industry 4.0 era: a general framework, in: 20th IFAC World Congress, volume 50, Elsevier B.V., 2017, pp. 5700–5705.
[12] G. Boothroyd, Use of Robots in Assembly Automation, CIRP Annals 33 (1984) 475–484.
[13] Z. M. Bi, W. J. Zhang, Flexible fixture design and automation: Review, issues and future directions, International Journal of Production Research 39 (2001) 2867–2894.
[14] K. M. Lee, Flexible part-feeding system for machine loading and assembly. Part I. A state-of-the-art survey, International Journal of Production Economics 25 (1991) 141–153.
[15] H. S. Kilic, M. B. Durmusoglu, Advances in assembly line parts feeding policies: A literature review, Assembly Automation 35 (2015) 57–68.
[16] D. Battini, M. Faccio, A. Persona, F. Sgarbossa, Design of the optimal feeding policy in an assembly system, International Journal of Production Economics 121 (2009) 233–254.
[17] A. C. Caputo, P. M. Pelagagge, P. Salini, Selection of assembly lines feeding policies based on parts features, in: 8th IFAC Conference on Manufacturing Modelling, Management and Control MIM, volume 49, Elsevier B.V., 2016, pp. 185–190.
[18] R. Hanson, L. Medbo, P. Medbo, Assembly station design: A quantitative comparison of the effects of kitting and continuous supply, Journal of Manufacturing Technology Management 23 (2012) 315–327.
[19] Y. Ho, A. S. El-Gizawy, A Programmable, Multi-Part Presentation System for Robot Assembly, IFAC Proceedings Volumes 27 (1994) 519–523.
[20] A. C. Sanderson, Parts entropy methods for robotic assembly system design, Proceedings - IEEE International Conference on Robotics and Automation (1984) 600–608.
[21] G. S. Chirikjian, Parts entropy and the principal kinematic formula, Applied and Numerical Harmonic Analysis (2012) 187–228.
[22] D. R. Berkowitz, J. Canny, Designing parts feeders using dynamic simulation, in: Proceedings of IEEE International Conference on Robotics and Automation, volume 2, 1996, pp. 1127–1132.
[23] J. Heilala, P. Voho, Modular reconfigurable flexible final assembly systems, Assembly Automation 21 (2001) 20–28.
[24] A. Bannat, T. Bautze, M. Beetz, J. Blume, K. Diepold, C. Ertelt, F. Geiger, T. Gmeiner, T. Gyger, A. Knoll, C. Lau, C. Lenz, M. Ostgathe, G. Reinhart, W. Roesel, T. Ruehr, A. Schuboe, K. Shea, I. Stork Genannt Wersborg, S. Stork, W. Tekouo, F. Wallhoff, M. Wiesbeck, M. F. Zaeh, Artificial cognition in production systems, IEEE Transactions on Automation Science and Engineering 8 (2011) 148–174.
[25] A. A. Malik, A. Bilberg, Framework to Implement Collaborative Robots in Manual Assembly: A Lean Automation Approach, in: International Symposium on Intelligent Manufacturing and Automation, 2017.
[26] I. Aaltonen, T. Salmi, I. Marstio, Refining levels of collaboration to support the design and evaluation of human-robot interaction in the manufacturing industry, Procedia CIRP 72 (2018) 93–98.
[27] W. Bauer, M. Bender, M. Braun, P. Rally, O. Scholtz, Lightweight robots in manual assembly – best to start simply, Examining companies' initial experiences with lightweight robots, Stuttgart (2016).
[28] A. Quenehen, J. Pocachard, N. Klement, Process optimisation using collaborative robots - comparative case study, in: 9th IFAC Conference MIM on Manufacturing Modelling, Management and Control, Berlin, 2019.
[29] G. Boothroyd, P. Dewhurst, C. Lennartz, Part Presentation Costs in Robot Assembly, Assembly Automation (1985) 138–146.
[30] M. Calzavara, R. Hanson, F. Sgarbossa, L. Medbo, M. I. Johansson, Picking from pallet and picking from boxes: a time and ergonomic study, 20th IFAC World Congress 50 (2017) 6888–6893.
[31] C. Finnsgård, C. Wänström, Factors impacting manual picking on assembly lines: An experiment in the automotive industry, International Journal of Production Research 51 (2013) 1789–1798.
[32] L. Bergamini, M. Sposato, M. Pellicciari, M. Peruzzini, S. Calderara, J. Schmidt, Deep learning-based method for vision-guided robotic grasping of unknown objects, Advanced Engineering Informatics 44 (2020) 101052.